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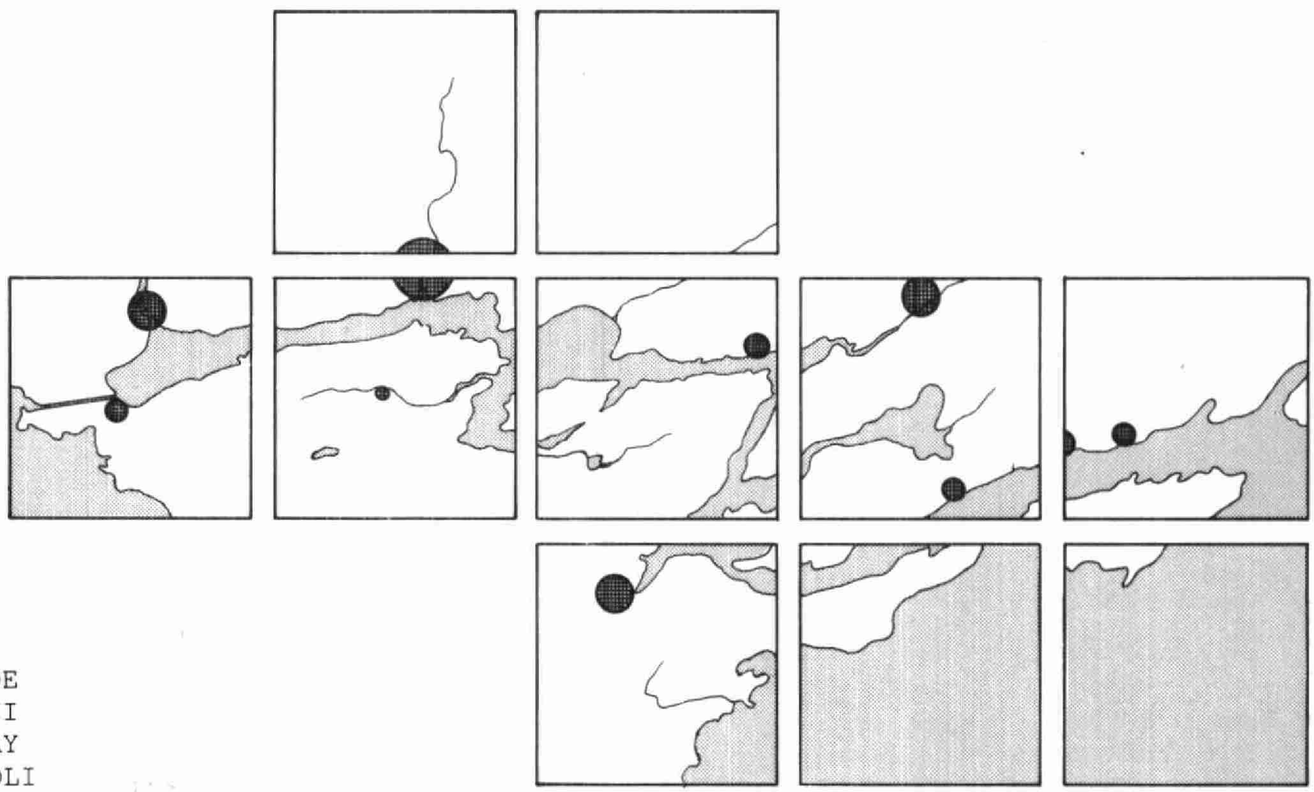
Bay of Quinte Remedial Action Plan

The Feasibility of Increasing The Hydrologic Flushing Rate of the Upper Bay of Quinte



Technical Report No. 3

BAY OF QUINTE REMEDIAL ACTION PLAN

THE FEASIBILITY OF INCREASING THE HYDROLOGIC FLUSHING RATE OF THE UPPER BAY OF QUINTE

Prepared for:

The Bay of Quinte RAP Coordinating Committee

By:

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FOREWORD

In its 1985 report to the International Joint Commission (IJC), the Great Lakes Water Quality Board recommended that the appropriate jurisdictions prepare and submit detailed Remedial Action Plans (RAPs) for the restoration of beneficial uses of 42 identified 'Areas of Concern' on the Great Lakes System. The Bay of Quinte is one of the IJC identified 'Areas of Concern'.

The process of developing a RAP for the Bay of Quinte was initiated in 1986 with the formation of a Federal/Provincial Coordinating Committee to oversee preparation of the RAP.

The Coordinating Committee in its February, 1987, Progress Report defined excessive nutrient enrichment, persistent toxics and bacteriological contamination as the factors responsible for the impairment of Bay of Quinte beneficial uses. It also identified technical data gaps and a list of potential options which required study.

This is one of a series of follow-up technical reports. It provides preliminary information concerning the feasibility and cost of enhancing water exchange by means of bringing Lake Ontario water into the Bay near Trenton. Enhancing the exchange of water through the Bay is one of the options which, in combination with point source nutrient control measures, offers the potential of achieving target water quality conditions in the Bay of Quinte. It should be understood that this report deals primarily with feasibility and, therefore, provides only a cursory evaluation of the environmental implications associated with bringing Lake Ontario water into the bay. A more detailed evaluation would be required before the option could be selected as a remedial measure.

It should be further noted that this report is only intended to serve as a background reference document. It provides useful information that will assist the Coordinating Committee and the public in evaluating the options and in ultimately defining a remedial action plan for the Bay. However, since a number of potential remedial options exist, it is important that the options not be screened in isolation. In order to facilitate the process of selecting the most desirable and cost effective combination of remedial measures for the Bay, two additional studies have been initiated for the purpose of synthesizing all of the

information. One is an ecosystem model which is intended to evaluate all of the options and provide predictions of their environmental benefits both individually and in combination. The second study is a socio-economic evaluation which is intended to provide an evaluation of the cost effectiveness of the options individually and in combination. It is expected that these two studies, drawing on the individual reference documents, will provide the integration and analyses and thus form the basis for a rational decision making process for the Bay of Quinte Remedial Action Plan.

If by means of the process described above, the option of bringing Lake Ontario water into the Bay is determined to be worthy of consideration as a reasonable means of achieving target water quality conditions, further detailed evaluation would be required to assess the overall environmental suitability of the option.

March, 1988
Bay of Quinte RAP Coordinating Committee

EXECUTIVE SUMMARY

Increasing the hydrological flushing rate of the Upper Bay of Quinte is an option being considered for remedial action in the bay. The feasibility of reducing the Upper Bay total phosphorus concentrations to 30 ug L^{-1} by flushing the Upper Bay using Lake Ontario water which has substantially lower phosphorus concentrations was investigated.

The reduction in Upper Bay mean total phosphorus concentration through increased flushing with Lake Ontario was determined assuming steady state conditions which assumes that phosphorus loadings are diluted with inflow to the bay. Total phosphorus loadings from the Trent, Moira, Salmon and Napanee Rivers; and sewage treatment plants at Belleville, Trenton, Napanee, Deseronto and the Canadian Forces Base - Trenton were used to assess the dilution requirements of the Upper Bay during the summer months May to October.

The effectiveness of reducing the nitrogen/phosphorus ratio of the Upper Bay through increased flushing was also investigated. Flushing was found to be an ineffective method for reducing the ratio below 12.

A flushing rate of 35 m^3 sec^{-1} was found to be adequate to reduce the Upper Bay total phosphorus concentrations to 30 ug L^{-1}. The costs of pumping Lake Ontario water at 20 and 35 m^3 sec^{-1} were investigated.

Various combinations of different intake locations (Barcovan Beach, Lake Ontario and Presqu'ile Bay), outfall locations (Upper Bay and Murray Canal) and different pipeline routes were investigated and prices. A summary of these options is as follows.

INTAKE LOCATION	OUTFALL LOCATION	CONVEYANCE
Barcovan Beach	Upper Bay	·Tunnel
Barcovan Beach	Upper Bay	·Open Cut along Road Allowances
Barcovan Beach	Murray Canal	·Tunnel
Presqu'ile Bay	Murray Canal	·Open Cut

Estimated construction costs varied between $12,700,000. and $44,600,000. with annual operating costs varying between $600,000. and $5,200,000.

The least expensive alternatives were those which considered pumping water from Presqu'ile Bay to the Murray Canal. Estimated construction costs varied between $12,700,000. and $13,400,000. with annual operating costs varying between $600,000. and $1,100,000. for flushing flows of 20 and 35 m^3 sec^{-1}, respectively. These options will improve the Presqu'ile Bay water quality as well. The environmental impact is small for these options provided proper construction techniques are used.

The additional cost of supplying Lake Ontario water directly to the water treatment plants in Trenton and Belleville was also considered. The preliminary total cost for this additional component is between $15,060,000. and $16,300,000. with annual operating costs estimated to be about $700,000.

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FEASIBILITY OF INCREASING THE HYDROLOGIC FLUSHING RATE OF THE UPPER BAY OF QUINTE

1.0 BACKGROUND

As described in the Bay of Quinte Remedial Action Plan: Progress Report (February 1987), point source phosphorus inputs have been substantially reduced since 1977. Present total phosphorus (TP) concentrations within the Bay, however, are still greater that the Provincial Water Quality Objectives of 20 ug L^{-1}. The sources of phosphorus loadings to the bay are the inflowing tributaries, many diffuse sources, sediments and atmospheric inputs.

One of the options for remedial action being considered for the Bay of Quinte is to increase the hydrologic flushing rate of the Upper Bay. Increased flushing of the Upper Bay using Lake Ontario water with substantially lower phosphorus concentrations could reduce TP concentrations in the Upper Bay and, therefore, change the trophic status of the bay.

The objectives of this projects are:

1. To determine the major engineering, environmental, jurisdictional and cost implications of pumping Lake Ontario water to replenish the Bay of Quinte water and, in effect, increase the flushing rate from the

Upper Bay; and,

2. To document some ancillary benefits which may result from this option.

2.0 MORPHOMETRY AND RETENTION TIME

The Bay of Quinte is usually discussed in terms of three geographical areas: Upper, Middle and Lower Bays. This study considers only the Upper Bay, which consists of the area from Trenton, past Belleville through Big Bay and past Deseronto to Mohawk Bay (Figure 1).

Morphometric parameters for the Upper Bay, as presented in Table 1, were determined using maps published by the Canadian Hydrographic Service. Water depths were corrected to adjust for differences between the map datum and the long term mean lake level at Kingston. The variation in the Upper Bay volume based on mean summer (May to September) and mean annual water levels was also considered. River inflows presented were obtained from Minns (1986) and, for comparison, the Water Survey of Canada data for 1985.

Four gauged rivers flow into the Upper Bay: the Trent, Moira, Salmon and Napanee. These rivers account for approximately 93% of the total drainage into the Bay of Quinte.

The Moira River has been gauged for the longest period of time, and records extend to 1916. Minns (1986) has computed

statistical variations for both summer and annual river flows. Month by month $\log_e/\log_e$ regressions of mean monthly flows were used to estimate mean monthly flow of the other rivers from 1916 to 1981 where gaps existed in the recorded data. Logarithmic means and standard deviations were then used to estimate likely low, mean and high annual and summer runoff. High and low flows were calculated as the mean plus of minus two standard deviations, respectively. These flows are presented in Table 1 with corresponding Upper Bay retention times.

Based on these flows, the mean retention time during the summer months varies from a minimum of one month to a maximum of about five months. When annual flows are considered the retention time is significantly lower varying between 0.5 and 1.5 months. Based on these high flushing rates, a steady-state dilution condition was assumed and, if the prime concern is TP concentrations in the Upper Bay of Quinte during the period May to September, point source loadings should be computed using data for that period.

3.0 PHOSPHORUS LOADINGS

Point source phosphorus inputs to the Upper Bay are the rivers and the sewage treatment plants (STP) which discharge to the Bay. Atmospheric loading, estimated at less than 2% of total loading (Minns, et. al., 1986) was ignored.

Phosphors removal efficiency at sewage treatment facilities has been increasing in recent years. In estimating TP loadings to the Bay, therefore, the most recent data is more appropriate.

3.1 River Loadings

TP loadings from river discharges were computed using TP concentration measurements taken at two separate sampling locations along each river (see Figure 1). Sampling locations closest to the river mouth were classified as Case I and those further upstream were classified as Case II. In all cases, mean values from data available between January 1984 to the present were used. Although river flow rates exhibit a seasonal variation with higher flows in the spring and lower flows in the winter, TP concentrations remain relatively constant throughout the year.

Average annual river flows as calculated by Minns (1986) were used to compute low, mean and high loading cases. Water Survey of Canada data for 1985 summer flows was also included. These loadings are summarized in Table 2 and Table 3 for Case I and Case II respectively.

For Case I, total average TP loadings vary from 965.4 mg sec^{-1} to 5266.9 mg sec^{-1}. For Case II total loadings vary from 1058.9 mg sec^{-1} to 5753.3 mg sec^{-1}. On average, TP concentrations for Case II are about 10% higher than Case I. The discrepancy in concentrations is, however, with the precision error of 10% that can be expected for concentrations of this magnitude.

3.2 Sewage Treatment Plant Loadings

Five STPs bounding the Upper Bay were noted in this report: direct discharges to the Upper Bay at Trenton, CFB Trenton, Belleville and Deseronto; and, the STP at Napanee discharging to the Napanee River.

Average summer (May to October) phosphorus loadings from the five sewage treatment plants were computed based on 1986

annual plant data records of flow and concentration. The loadings are summarized on Table 4. The five plants show a combined average total phosphorus loading of 673.5 mg sec^{-1}.

4.0 BACKGROUND CONCENTRATIONS IN THE UPPER BAY AND LAKE ONTARIO

In assessing the benefits and feasibility of increasing the flushing rate of the Upper Bay it is important to compare background concentrations both in the Upper Bay and in the vicinity of Lake Ontario from which flushing water would be obtained.

4.1 Background Concentrations in the Upper Bay

Table 5 presents average background concentrations of TP and total kjeldahl nitrogen (TKN) in the Upper Bay near Trenton, Belleville and Napanee. TP concentrations in the Upper Bay average about 50 ug L^{-1}, and the Nitrogen to Phosphorus (N/P) ratio for the Upper Bay is about 14.

4.2 Background Concentrations in Lake Ontario

To be a viable supply there must be no negative environmental impacts at the supply source, and the flushing water must: (1) have lower TP concentrations than the Upper Bay; and, (2) be as close to the Upper Bay as possible. It is thus proposed that the source of flushing water be located within

the near shore waters of Lake Ontario within the area bounded by Presqu'ile Bay to the west and Wellington village to the east.

Most recent average TP concentrations within this area of Lake Ontario were obtained from a report being prepared for the Lake Ontario Task Force and the Surveillance Working Group at the International Joint Commission (1987). In 1985, TP concentrations were shown to average 11.9 ug L^{-1}. As well, the Nearshore Water Quality Atlas (1976-79) shows TKN concentrations to average about 247 ug L^{-1} within this area. Thus, the N/P ratio in the bounded area measures approximately 20.

5.0 FLUSHING RATES TO REDUCE UPPER BAY PHOSPHORUS CONCENTRATIONS

The reductions in Upper Bay mean TP concentration through increased flushing with Lake Ontario water was computed assuming steady state dilution. As such, total loadings into the Upper Bay were assumed to be diluted by the total inflows. The summer retention times for the Upper Bay are between 1 and 5 months for the high and low river flows respectively. Steady state dilution is an approximation. Steady state or equilibrium conditions do not exist in a large body of water like the Upper Bay where the discharges, water levels and currents vary with time and sediments can act both as a source and sink varying with time. However, a dynamic mass balance analysis for the Upper Bay would require a dynamic mass balance numerical model with the kinetics of the various sources and sinks quantified. A steady state dilutions does, however, permit a preliminary assessment of the feasibility of the flushing option. If this option is to be investigated further, detailed analyses using dynamic models would be required. An assumption of steady state dilution is more justified for the shorter retention periods, particularly to determine the feasibility of flushing to reduce phosphorus concentrations in the Upper Bay. The Upper

Bay mean phosphorus concentrations was therefore computed as:

$$C_{U.B.} = \frac{C_{L.ONT.} * Q_O + \sum_{1}^{NRIVERS} C_R * Q_R + \sum_{1}^{NSTP} C_{STP} \times Q_{STP}}{Q_O + \sum_{1}^{NRIVERS} Q_R + \sum_{1}^{NSTP} Q_{STP}} \qquad (1)$$

where:

$C_{U.B.}$	=	mean total phosphorus concentration ([P]) within the Upper Bay
$C_{L.ONT.}$	=	[P] of the Lake Ontario flushing water
C_R	=	[P] of each specific river flowing into the Upper Bay
C_{STP}	=	[P] of each STP discharging into the Upper Bay
Q_O	=	flushing flow rate
Q_R	=	mean summer river flow
Q_{STP}	=	mean STP flow
NRIVERS	=	number of gauged rivers discharging into the Upper Bay (4)
NSTP	=	number of STPs discharging into the Upper Bay (5)

Two cases are considered, where Case I and Case II represent loadings based on river phosphorus data obtained near each

river outlet and further upstream respectively (see Figure 1).

For each case, four different summer river flows were used. Low, mean and high flows from Minns (1986) and 1985 mean summer flows are presented in Table 1.
Loadings from sewage treatment plants were based on the most recent available plant data of effluent concentration and flow rate. The data are presented in Table 4.

The source of Lake Ontario flushing water was assumed to have an average total phosphorus concentration of 12.0 ± 3.0 ug L^{-1}.

Figures 2 and 3 show the impact of different flushing rates on Upper Bay TP concentrations for the different river flows. The curves flatten as the flushing flows approach the river flows. In other words, the flushing water flows decrease the Upper Bay TP concentrations less as flushing flows approach the river flows. This is expected because the river TP loadings represent approximately 80% of the TP loadings to the bay for the mean river flow condition. When the river flows are low, flushing is much more effective in reducing Upper Bay TP concentrations (see Figures 2 and 3).

Because the mean TP concentration of the Trent River is 30 ug L^{-1} and the mean flow in the Trent River is over 80% of the total river flow to the Bay, the Trent River is, thus, the main factor in determining the Upper Bay TP concentrations if the phosphorus loading from sediments is not considered. The mean TP concentration of 30 ug L^{-1} in the Trent River does not achieve provincial receiving water objectives.

Ideally, the flushing flow rates should reduce Upper Bay TP concentrations to less than 30 ug L^{-1}. Figure 2 shows that a flushing low of 35 m^3 sec^{-1} is required for Case I and greater than 40 m^3 sec^{-1} for Case II. The difference in TP river loadings in Case II is about 10% greater than Case I. The calculated difference is due to a 10% difference in TP concentrations measurements, and also, is indicative of the precision and sensitivity of the TP analyses in determining the required flushing flow using a steady state dilution approach.

Another approach suggested by Minns is to select a flushing rate that will produce Upper Bay TP concentrations equivalent to the river concentrations. However with the Trent River contributing 80% of the phosphorus loading to the

Bay and having a mean TP concentration of 30 ug L^{-1}, this option is the same as the preceding condition.

Thus, a flushing flow of 35 m^3 sec^{-1} will achieve Upper Bay TP concentrations of 30 ug L^{-1} for all river loadings considered in Case I. As well, a smaller flushing flow of 20 m^3 sec^{-1} will produce Upper Bay TP concentrations between 31 and 35 ug L^{-1} for high and low river flows respectively. Furthermore, if phosphorus removal was installed at the Napanee STP and phosphorus removal efficiency improved at the Belleville STP from 575 to 300 ug L^{-1}, the total STP loadings would be reduced by 54% to 309 mg sec^{-1}. In this case a flushing rate of 20 m^3 sec^{-1} will produce Upper Bay TP concentrations of 29.4 to 28.5 ug L^{-1} for high and low river flows respectively.

6.0 UPPER BAY N/P RATIO VARIATION WITH INCREASED FLUSHING

The change in the Upper Bay N/P ratio through increased flushing with Lake Ontario was also computed assuming steady state dilution. The major Upper Bay inflow sources of both nitrogen and phosphorus were assumed to be the same. The Upper Bay N/P ratio was computed therefore as:

$$N/P = \frac{N_{L.ONT.} \times Q_{O} + N_{U.B.} \left(\sum_{1}^{NRIVERS} Q_{R} + \sum_{1}^{NSTP} Q_{STP} \right)}{P_{L.ONT.} \times Q_{O} + \sum_{1}^{NRIVERS} P_{R} \times Q_{R} + \sum_{1}^{NSTP} P_{STP} \times Q_{STP}}$$

where:

N/P = total nitrogen to total phosphorus ratio within the Upper Bay

$N_{L.ONT.}$ = average total nitrogen concentration ([N]) of Lake Ontario flushing water

$N_{U.B.}$ = [N] within the Upper Bay

$P_{L.ONT.}$ = average total phosphorus concentration ([P]) of the Lake Ontario source water

P_{R} = [P] of each specific river flowing into the Upper Bay

P_{STP} = [P] of each STP discharging into the Upper Bay

Q_{O} = flushing flow rate

Q_{R} = mean summer river flow

Q_{STP} = mean STP flow

NRIVERS = number of gauged rivers discharging into

the Upper Bay (4)

NSTP = number of STPs discharging into the Upper Bay (5)

For these computations, Case II river loadings were used. Four different summer river flows were also considered. TP loadings from low, mean and high flows (Minns, 1986) and 1985 mean summer flows are presented in Table 3.

TP loadings from sewage treatment plants were based on the most recent available plant data of effluent concentration and flow rate. The data are presented in Table 4.

The source of Lake Ontario flushing water was assumed to have an average TKN concentration of 250 ug L^{-1} and average TP concentration of 12.0 ug L^{-1}. The background Upper Bay TKN was assumed to be 700.0 ug L^{-1}.

Figure 4 presents a summary of the variation in the Upper Bay N/P ratio for increasing flushing flow rates.

For zero flushing, the Upper Bay N/P ratio varies from about 13.3 to 19.4 depending on the river discharge flow regime. In each case however, the N/P ratio increases mildly for increasing flushing flow. At a flushing rate of 35 m^3 sec^{-1}

for example, the N/P ratio varies from about 14.8 for the low river discharge to about 19.5 for the high river discharge regime. Flushing, therefore, cannot be considered an effective method for reducing the N/P ratio below 12.

7.0 OPTIONS AND COST ESTIMATES

Several locations along the Lake Ontario near shore from Presqu'ile Bay to Wellington village were considered as possible sources of flushing water (see Figure 5).

If assessed in terms of water quality only, a source near Wellington would provide the best flushing water. However, a Wellington source would require a pipe line about 22 kilometers long to connect the source to the Upper Bay, a distance approximately twice that of other possible options and sites considered.

A plan view of the ten options considered is presented in Figure 6. Corresponding cost estimates are summarized in Table 6. Operating costs presented in Table 6 are based on 12 months. If flushing is employed only for the months May through September, operating costs are reduced correspondingly by approximately 60%.

7.1 Piping Flushing Water to the Upper Bay

Options 1 to 6 (see Figure 6) consider the costs of pumping water from Lake Ontario, offshore of Barcovan Beach, and

piping it to a location South-West of Indian Island in the Upper Bay. Flushing water would be drawn at a depth in Lake Ontario of about 7.6 meters through an intake with small entrance velocities. A simple diffuser, designed to maximize dilution and minimize induced currents, would be used to discharge the water into the Upper Bay at a depth of about 3.4 meters.

Options 1 through 6 consider the various costs of providing flushing water at rates of 20 and 35 m^3 sec^{-1}. For flushing flows of 20 m^3 sec^{-1}, cost estimates are provided for pipe diameters of 3.05 and 3.66 meters, while for a flow rate of 35 m^3 sec^{-1} costs are estimated for a pipe 3.66 meters in diameter only. Cost estimates of (1) constructing a pumping station near the Lake Ontario shore, (2) pump installation, and (3) annual operating costs for the different system are also provided.

Options 1 to 3 consider the costs of tunneling through rock and installing a concrete liner for a length of about 8960 meters (29400 feet) extending from Barcovan Beach on Lake Ontario to Twelve O'Clock Point on the Upper Bay. The tunnel option would have the least impact on the local environment and would not require obtaining rights-of-way and easements.

Options 4 to 6 consider the costs of escavating an open cut trench and laying a concrete pressure pipe. The route assessed for this option follows existing roadways from the Lake Ontario shoreline at Barcovan Beach to Twelve O'Clock in the Upper Bay; a distance covering about 10850 meters (35600 feet). A pipe layed within the existing road allowances would extend the distance to be covered but, on the other hand, facilitate construction and reduce local environmental impacts.

For a flushing flow rate of 20 m^3 sec^{-1}, the estimated construction costs vary form $31,900,000. to $40,500,000. with annual operating costs ranging from $1,000,000. to $3,800,000 (see Table 6). For this flow rate, Option 2 (3.66 meter diameter, concrete line tunnel) is the least expensive of the options with construction costs of $36,000,000. and considering the annual operating costs of $1,000,000. Within a period of about 4 years the savings from lower operating costs would offset the increased construction costs.

For a flow rate of 35 m^3 sec^{-1}, Option 3 (3.66 meter diameter, concrete lined tunnel) is the least expensive alternative with estimated construction and operating costs

of about $39,700,000. and $5,200,000., respectively.

7.2 Using the Murray Canal to Channel the Flushing Water

Another option assessed was using the Murray Canal as an open channel to provide flushing water drawn from either Presqu'ile Bay (Options 7 and 8) or Lake Ontario, offshore of Barcovan Beach (Options 9 and 10). To make these options effective two sets of boater-operated lock gates, similar to those currently used in the Trent-Severn Waterway, must be installed at the western end of the Murray Canal.

Using maps published by the Canadian Hydrographic Service and correcting the depth for long term mean summer lake levels, the volume of Presqu'ile Bay was estimated at 22.3×10^6 m^3. The retention time is Presqu'ile Bay thus is approximately 7 days and 13 days for flushing flows of 35 and 20 m^3 sec^{-1}, respectively. Implementation of either options 7 or 8 would, within a relatively short time, draw Lake Ontario water through Presqu'ile Bay into the Murray Canal. These options, therefore, have the ancillary benefit of improving the water quality of Presqu'ile Bay as well.

In Options 7 and 8, an intake pipe extending about 1.5 km southwest of Sherwood Point would be tunneled to the deeper waters of Presqu'ile Bay. The pipe entrance would be fitted with an intake structure designed to minimize entrance velocities. As well, a pumping station would be located at Sherwood Point to pump flushing water through a discharge structure in the Murray Canal. The discharge structure would be (1) designed to minimize local velocities and (2) positioned downstream of the lock gates.

Options 9 and 10 consider the cost of tunneling through rock and installing a 3.66 diameter concrete liner for a length of about 4400 meters (14400 feet) extending from Barcovan Beach to the western end of the Murray Canal. Flushing water would be drawn at a depth on Lake Ontario of about 7.6 meters through an intake structure designed to minimize entrance velocities. A pumping station would be located near the Lake Ontario shore pumping flushing water to a discharge structure in the Murray Canal. As above, the discharge structure would be (1) designed to minimize local velocities and (2) located downstream of the lock gates.

The induced current within the canal is a consideration for navigation. Based on preliminary calculations, a relatively

small current of about 1 km $hour^{-1}$ would be induced for a flushing flow of 35 m^3 sec^{-1}.

Comparing Options 7 through 10, the total distance between the intake and discharge structures is relatively short for Options 7 and 8 and, thus, construction costs are minimized. Options 7 and 8 are the least expensive alternatives with construction costs ranging between $12,700,000. and $13,400,000. and annual operating costs varying between $600,000. and $1,100,000. for flushing flows of 20 and 35 m^3 sec^{-1}, respectively.

7.3 Environmental and Jurisdictional Implications

From the preliminary evaluation, the least expensive Options 7 and 8 appear to have the least potential for environmental impact. With a properly designed intake, Options 7 and 8 should not impact the fisheries in Presqu'ile Bay, and as stated previously, these options have a further benefit of improving the water exchange in Presqu'ile Bay.

With respect to jurisdictional responsibilities, most of the construction for Options 7 and 8, with the exception of the locks and pumping stations, are marine works in a relatively small area of Presqu'ile Bay. Water lot permits will be required from the Ministry of Natural Resources. Also, permits will be required from the authorities (Parks Canada) regulating the Murray Canal.

Options 1 to 6, 9 and 10 all have offshore intake (requiring a water lot permit from the Ministry of Natural Resources) and a pump house on the shore. Construction of the tunnel in Options 1 to 3 likely will have a minimal environmental impact although water to permits would be required for the discharge in the Upper Bay. There will also be some environmental impact during the construction of the outfall. However, these impacts can be minimized by proper construction techniques. Options 4 to 6 require the installation of pipelines using open cut techniques. Although the routes selected follow road allowances to minimize the environmental impact, there will be a disruption of traffic and construction permits will be required fro the various counties. The laying of pipelines in road allowances, however, is a common practice and construction techniques have been developed to minimize the environmental

impact. Options 9 and 10 use a tunnel from the pump house to the Murray Canal. Consequently, these options avoid the disturbance of open cut pipeline construction. Tunnels are preferred to open cut pipeline construction to minimize the environmental impact. However, the tunnelling options is more expensive.

7.4 Cost of Supplying Lake Ontario Water to WTP in Trenton and Belleville

The additional cost of supplying Lake Ontario water directly to water treatment plants in Trenton and Belleville in an effort to provide an alternative and, perhaps, improved drinking water supply to these municipalities was also considered (see Figure 7). The 1.0 m^3 sec^{-1} current design capacity of municipal waterworks for the two cities combined is negligible when compared to the flushing flow requirements. As such, cost estimates were based on the construction requirements of connecting a 0.91 m diameter water main to any one of the flushing pipelines proposed in Options 1 to 6. The pipeline would follow major roads to the Trenton WTP, thereby, using existing road allowances and minimizing environmental impacts. A booster pumping station for this water main would be installed in an area northwest

of Carrying Place. If Options 7 to 10 are used, the water main would draw water directly out of the eastern end of the Murray Canal and a pumping station could be located near Twelve O'Clock Point.

From the Trenton WTP a 0.76 m diameter line would follow the Canadian Pacific Railway line into Belleville at which point major roads would be followed to the Belleville WTP. This route generally is the most direct taking into account the topography and location of the existing WTPs.

The total estimated cost for this component is about $16,300,000. with annual operating costs of about $700,000. if added to Options 1 to 6. The shorter pipe length required for options 7 to 10 would result in a saving of about $1,240,000. in construction costs. Additional savings may result if Lake Ontario water is piped directly to the Belleville WTP.

8.0 SUMMARY

The reduction in Upper Bay mean TP concentrations through increased flushing with Lake Ontario water was computed assuming steady state dilution. Current loadings to the Upper Bay were based on the most recent available data. It was therefore determined that at a flushing flow of 35 m^3 sec^{-1}, the Upper Bay TP concentrations can be reduced to less than 30 ug L^{-1}. If, however, phosphorus removal was installed at the Napanee STP and phosphorus removal efficiency improved at the Belleville STP, and additionally, at the Trenton STP, a flushing rate of 20 m^3 sec^{-1} could be employed to reduce the Upper Bay TP concentrations to less than 30 ug L^{-1}.

The estimated total construction and annual operating costs in providing flushing flow to the Upper Bay at rates of 20 and 35 m^3 sec^{-1} were considered for several options.

The least expensive alternative, both from a construction and operating cost perspective, are Options 7 and 8. In these options, the Murray Canal would be used as an open channel to provide the Upper Bay with flushing water drawn from Presqu'ile Bay. An intake pipe extending about 1.5 km would be tunneled to the deeper waters of Presqu'ile Bay.

The pipe entrance would be fitted with an intake structure designed to minimize entrance velocities. A pumping station would be constructed at Sherwood Point to pump flushing water through a discharge structure designed to minimize local velocities in the Murray Canal. To make this option effective, two sets of boater-operated lock gated positioned at the western end of the Murray Canal would be required. A relatively small current of about 1 km $hour^{-1}$ would be induced in the Murray Canal when a flushing flow of 35 m^3 sec^{-1} is employed.

The volume of Presqu'ile Bay is small compared to the flushing water flows requirements, and therefore, water retention time in Presqu'ile Bay is shorter. Lake Ontario water thus would be drawn through Presqu'ile Bay within 7 to 13 days at flushing flow rates of 35 and 20 m^3 sec^{-1}, respectively. Therefore, the option drawing flushing water from Presqu'ile Bay could have the ancillary benefit of improving the water quality of Presqu'ile Bay.

A preliminary total cost of the Presqu'ile Bay-pipeline option was estimated to be between $12,700,000. and $13,400,000. with annual operating costs between $600,000. and $1,100,000. for flushing flows of 20 and 35 m^3 sec^{-1},

respectively. This option implemented only for the months May through would reduce operating costs by about 60%.

The additional cost of supplying Lake Ontario water directly to WTPs in Trenton and Belleville was considered. If Options 7 to 10 are adopted, a water main could draw water directly out of the eastern end of the Murray Canal. A pumping station for this water main could be located near Twelve O'Clock Point. The proposed route for the water main is generally the most direct taking into account the topography and the location the existing WTPs. The preliminary total cost for this additional work is between \$15,060,000. and \$16,300,000. with annual operating costs estimated to be about \$700,000.

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TABLE 1

ESTIMATED SURFACE AREA, VOLUME, RIVER INFLOWS AND RETENTION TIME FOR UPPER BAY OF QUINTE

	SURFACE AREA (km^2)	MEAN WATER LEVEL ABOVE CHART DATUM [1] (m)	VOLUME ($x10^6$ m^3)	RIVER FLOWS (m^3/s)	RETENTION TIME (days)
SUMMER (May-Sept.)	134.5	0.78	470.0	Low = 32.2[2] Mean = 74.0[2] High = 177.0[2] 1985 = 114.2[3]	168.9 73.5 30.7 47.6
ANNUAL	134.5	0.59	448.8	Low = 110.1[2] Mean = 182.0[2] High = 300.9[2] 1985 = 255.4[3]	47.2 28.5 17.3 20.3

[1] from Canadian Hydrographic Service for 1986

[2] from Minns, 1986

[3] from Water Survey of Canada for 1985

TABLE 2

RIVER - PHOSPHORUS LOADINGS - CASE I

	Avg. P[1] Concentration (mg/m^3)	SUMMER FLOWS - (Minns, 1986) LOW Q (m^3/s)	Loading (mg/s)	MEAN Q (m^3/s)	Loading (mg/s)	HIGH Q (m^3/s)	Loading (mg/s)	1985 Water Survey of Canada Summer Flows Q (m^3/s)	Loading (mg/s)
Trent @ (0.805 km)	30.0	28.5	855.0	61.0	1830.0	130.7	3921.0	96.2	2886.0
Moira @ (1.127 km)	29.0	2.5	72.5	8.3	240.7	27.7	803.3	12.8	371.2
Salmon @ (2.897 km)	24.0	0.5	12.0	2.4	57.6	11.2	268.8	2.7	64.8
Napanee @ (22.53 km)[2]	37.0	0.7	25.9	2.3	85.1	7.4	273.8	2.5	92.5
		32.2		74.0		177.0		114.20	
Totals			965.4		2213.4		5266.9		3414.5

[1] Ontario Ministry of the Environment Sample Information System, Bay of Quinte Tributary Water Quality Data

[2] insufficient data at near-mouth station

TABLE 3

RIVER - PHOSPHORUS LOADINGS - CASE II

	Avg. P[1] Concentration (mg/m^3)	SUMMER FLOWS - (Minns, 1986) LOW Q (m^3/s)	LOW Loading (mg/s)	MEAN Q (m^3/s)	MEAN Loading (mg/s)	HIGH Q (m^3/s)	HIGH Loading (mg/s)	1985 Water Survey of Canada Summer Flows Q (m^3/s)	Loading (mg/s)
Trent @ (3.862 km)	33.0	28.5	940.50	61.0	2013.00	130.7	4313.10	96.2	3174.60
Moira @ (6.276 km)	32.0	2.5	80.00	8.3	265.60	27.7	886.40	12.8	409.60
Salmon @ (4.989 km)	25.0	0.5	12.50	2.4	60.00	11.2	280.00	2.7	67.50
Napanee @ (22.53 km)	37.0	0.7	25.90	2.3	85.10	7.4	273.80	2.5	92.50
		32.2		74.0		177.0		114.20	
Totals			1058.90		2423.70		5753.30		3744.20

[1] Ontario Ministry of the Environment Sample Information System, Bay of Quinte Tributary Water Quality Data

TABLE 4

STP - PHOSPHORUS LOADINGS

(May to October, 1986 averages)

	P (mg/m^3)	Q (m^3/s)	LOADINGS (mg/s)
BELLEVILLE	575.0	0.520	299.0
TRENTON	340.0	0.136	46.3
NAPANEE	2380.0	0.118	280.8
DESERONTO	480.0	0.017	8.2
CFB TRENTON	560.0	0.070	39.2
TOTALS		0.861	673.5

TABLE 5

RECEIVING WATER CONCENTRATIONS

		TOTAL P[1] (mg/l)	TKN[1] (mg/l)
BELLEVILLE	1986	0.033	0.60
	1985	0.051	0.79
	1984	0.054	0.80
	1983	0.053	0.65
	1982	0.060	0.64
	Mean:	0.050	0.70
NAPANEE	1982	0.051	0.72
TRENTON (July 19 only)	1983	0.047	0.57

[1] Ontario Ministry of the Environment Internal Report on the Bay of Quinte

TABLE 6
COST CONSIDERATIONS

Option Number	Description	Flow Rate (m^3/s)	Pipe Diameter (m)	Pipe Length (m)	Pump Requirements (Horsepower)	Pipe Cost ($ million)	Pump House Cost ($ million)	Preliminary Estimated Total Cost ($ million)	Est. Annual Operating Cost ($ million)
1	- tunnel in rock - installing concrete liner - from Barcovan Beach (L.Ont.) to Twelve O'Clock Pt. (Upper Bay)	20	3.05 (10.0 ft)	8961 (29400 ft)	5000	27.3	4.6	31.9	2.1
2	"	20	3.66 (12.0 ft)	8961 (29400 ft)	2100	32.8	3.2	36.0	1.0
3	"	35	3.66 (12.0 ft)	8961 (29400 ft)	11000	32.8	6.9	39.7	5.2
4	- open cut and install concrete pressure pipe - from Barcovan Beach (L.Ont.) to Twelve O'Clock Pt. (Upper Bay)	20	3.05 (10.0 ft)	10851 (35600 ft)	7800	29.9	5.3	35.2	3.8
5	"	20	3.66 (12.0 ft)	10851 (35600 ft)	4200	35.9	4.6	40.5	2.1
6	"	35	3.66 (12.0 ft)	16200 (35600 ft)	16200	35.9	8.7	44.6	7.6
7	- install lock gates on Murray Canal - pump water from Presqu'ile Bay into Murray Canal	20	3.66 (12.0 ft)	2000 (6563 ft)	1200	7.3	3.5	12.7[2]	0.6
8	"	35	3.66 (12.0 ft)	2000 (6563 ft)	2200	7.3	4.1	13.4[2]	1.1
9	- install lock gates on Murray Canal - pump water from Barcovan Beach (L. Ont.) to Murray Canal	20	3.66 (12.0 ft)	4300 (14100 ft)	1100	15.7	3.2	20.9[2]	0.6
10	"	35	3.66 (12.0 ft)	4300 (14100 ft)	5500	15.7	4.8	22.5[2]	2.9
	Cost of supplying Trenton & Belleville with L.Ont. water - connecting watermain to either of options 1 - 6 - use 36" conduit to Trenton - use 30" conduit from Trenton to Belleville	1.01	0.91 (3.0 ft) 0.76 (2.5 ft)	11887 (39000 ft) 4816 (15800 ft)	1500	9.8 3.3	3.2	16.3	0.7

Note: 1 - estimated current design capacity of municipal water works including approximately 0.4 m^3/s for Trenton and 0.6 m^3/s for Belleville obtained from the National Inventory of Municipal Waterworks and Wastewater Systems in Canada 1986.

2 - includes estimated 2.0 million dollars for 2 sets of lock gates installed on the Murray Canal.

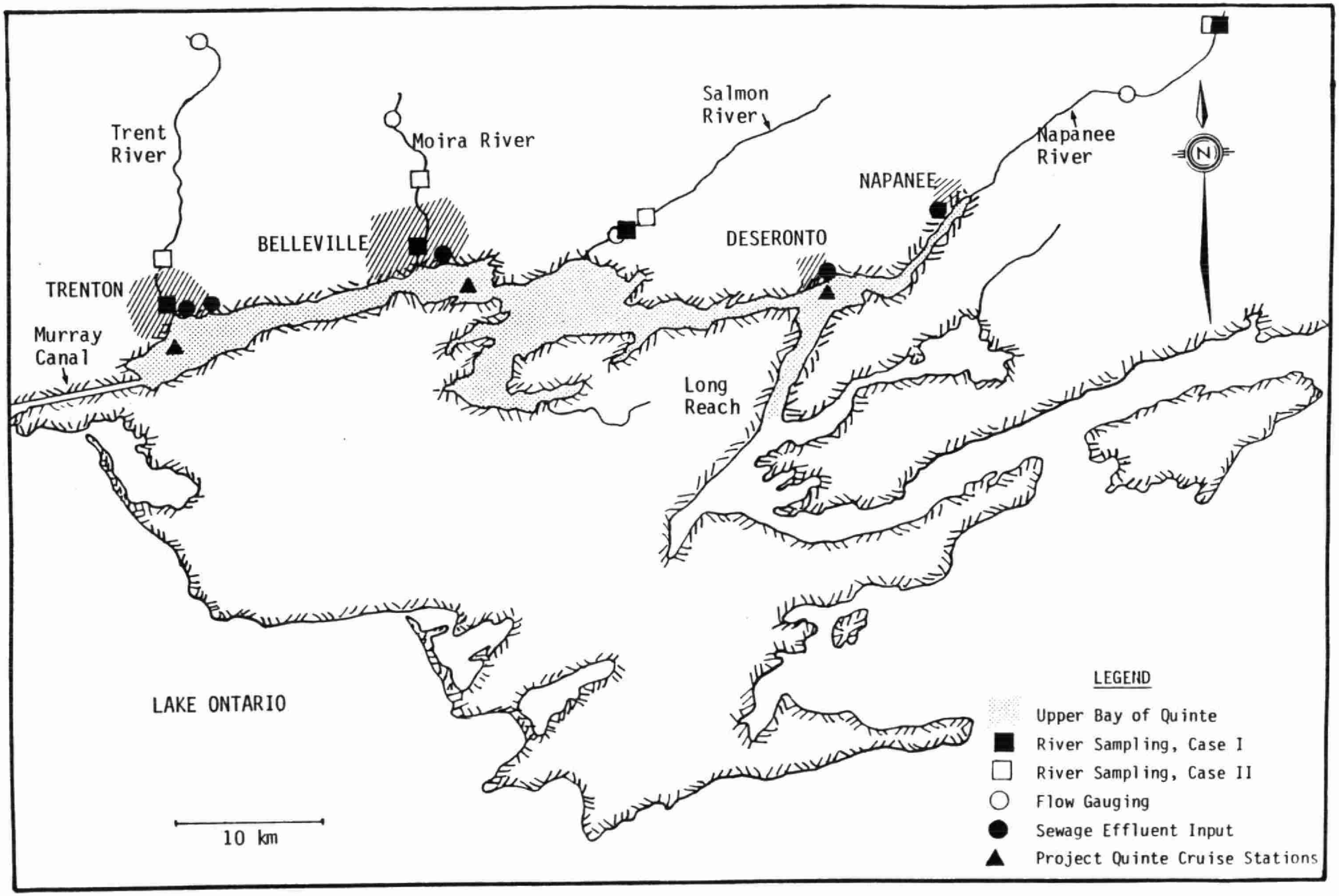

Figure 1 Upper Bay of Quinte, showing the location of point sources and sampling stations.

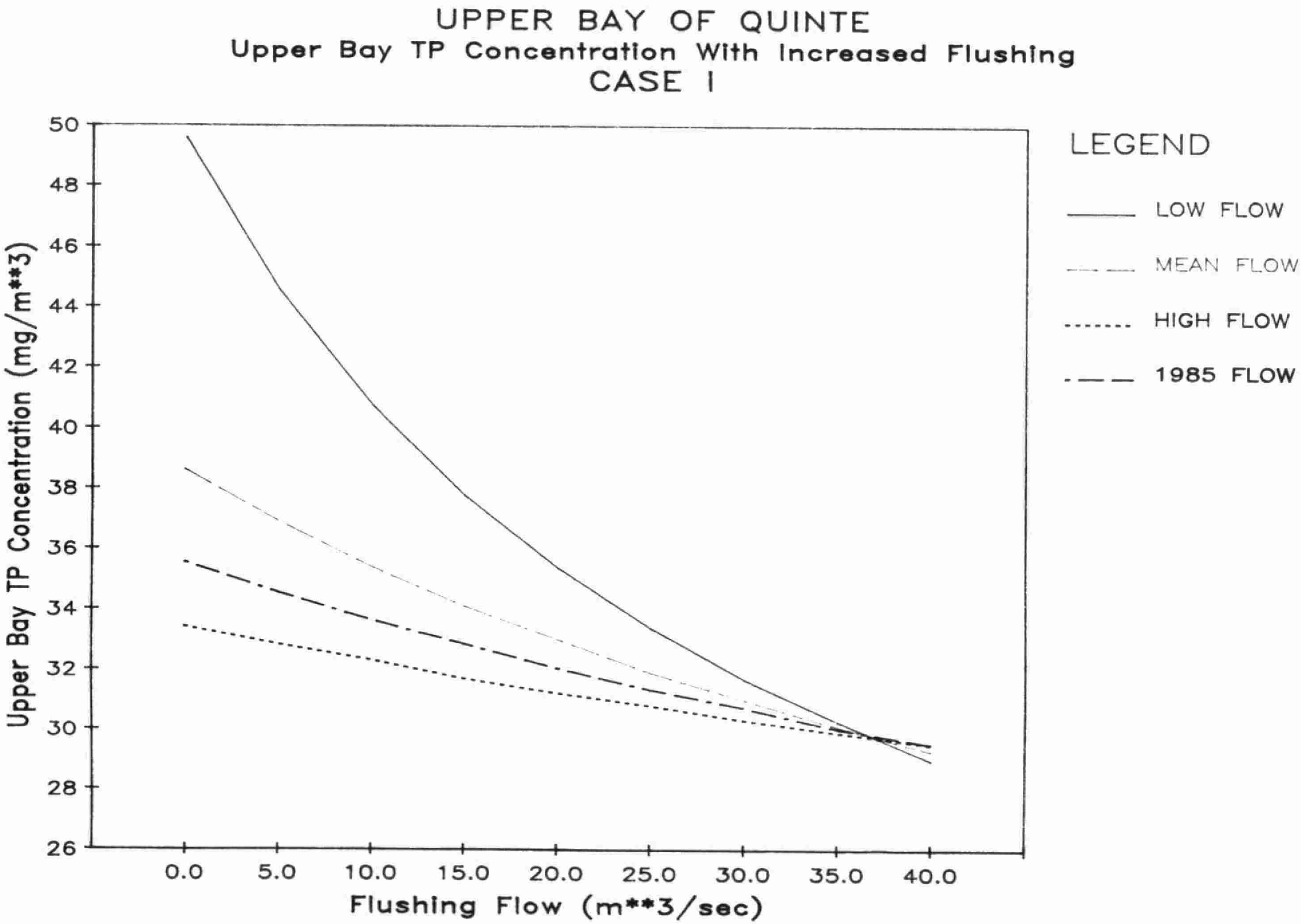

Figure 2 Upper Bay TP concentration with increased flushing – Case I.

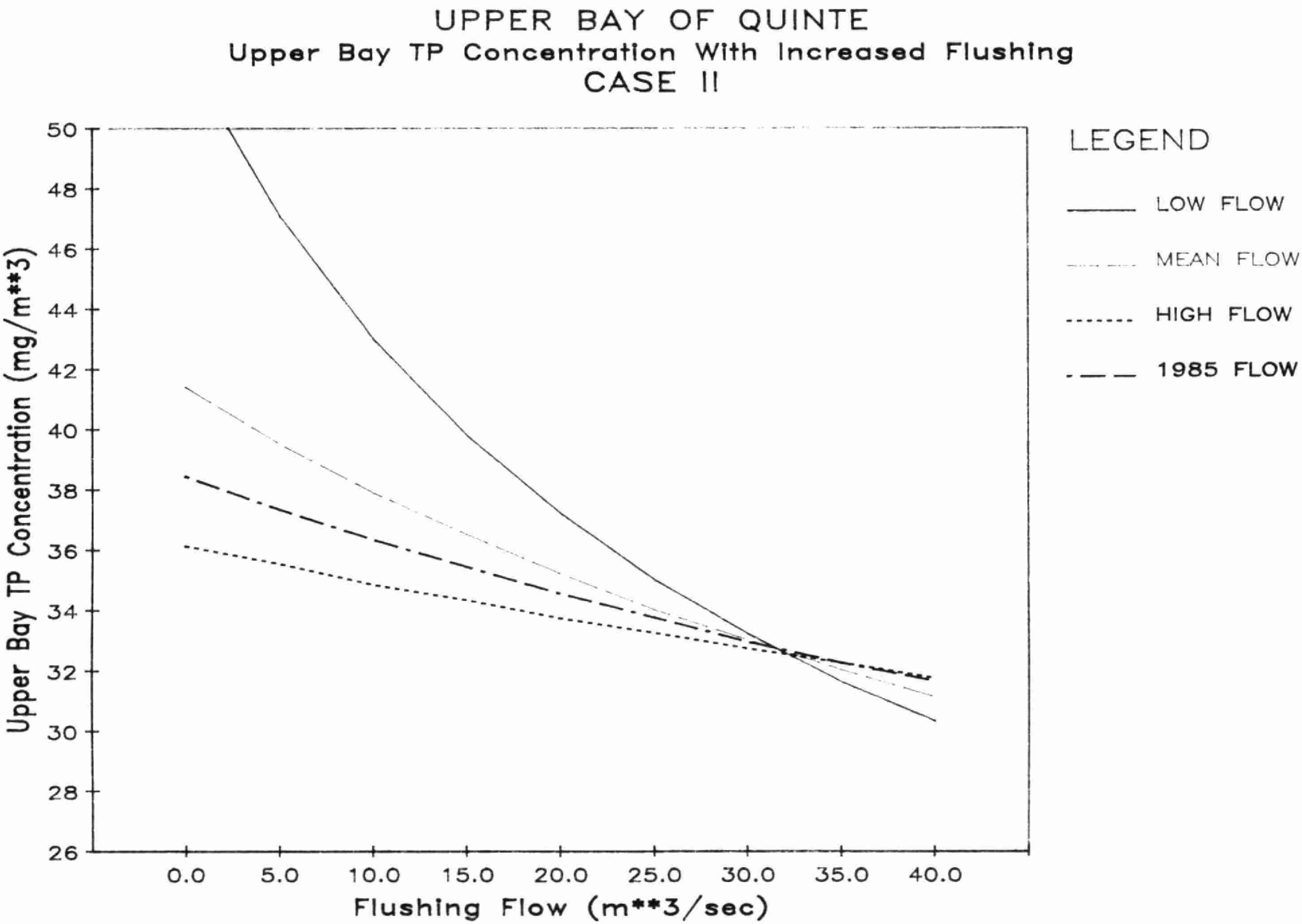

Figure 3 Upper Bay TP concentration with increased flushing — Case II

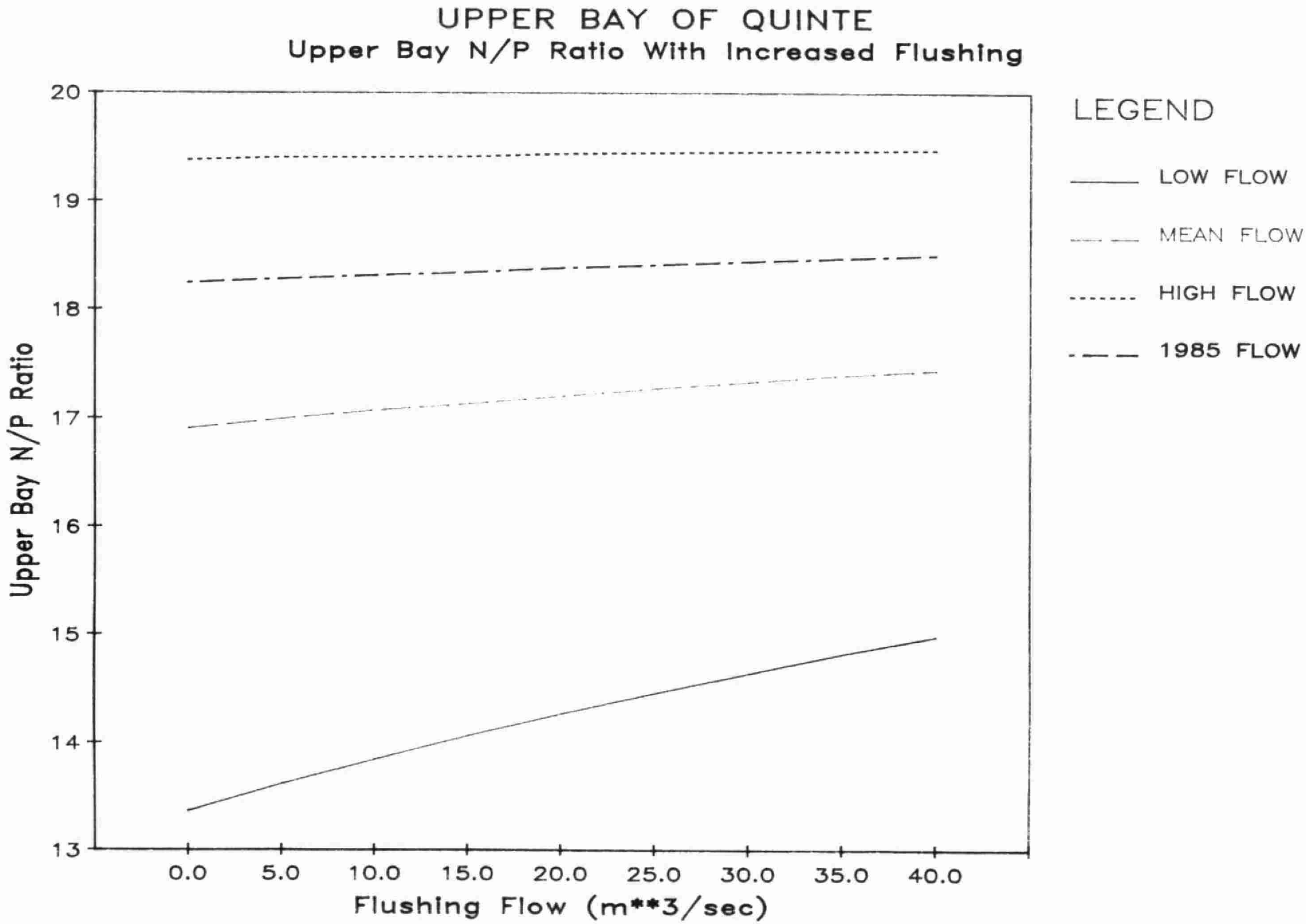

Figure 4 Upper Bay N/P Ratio with Increased Flushing

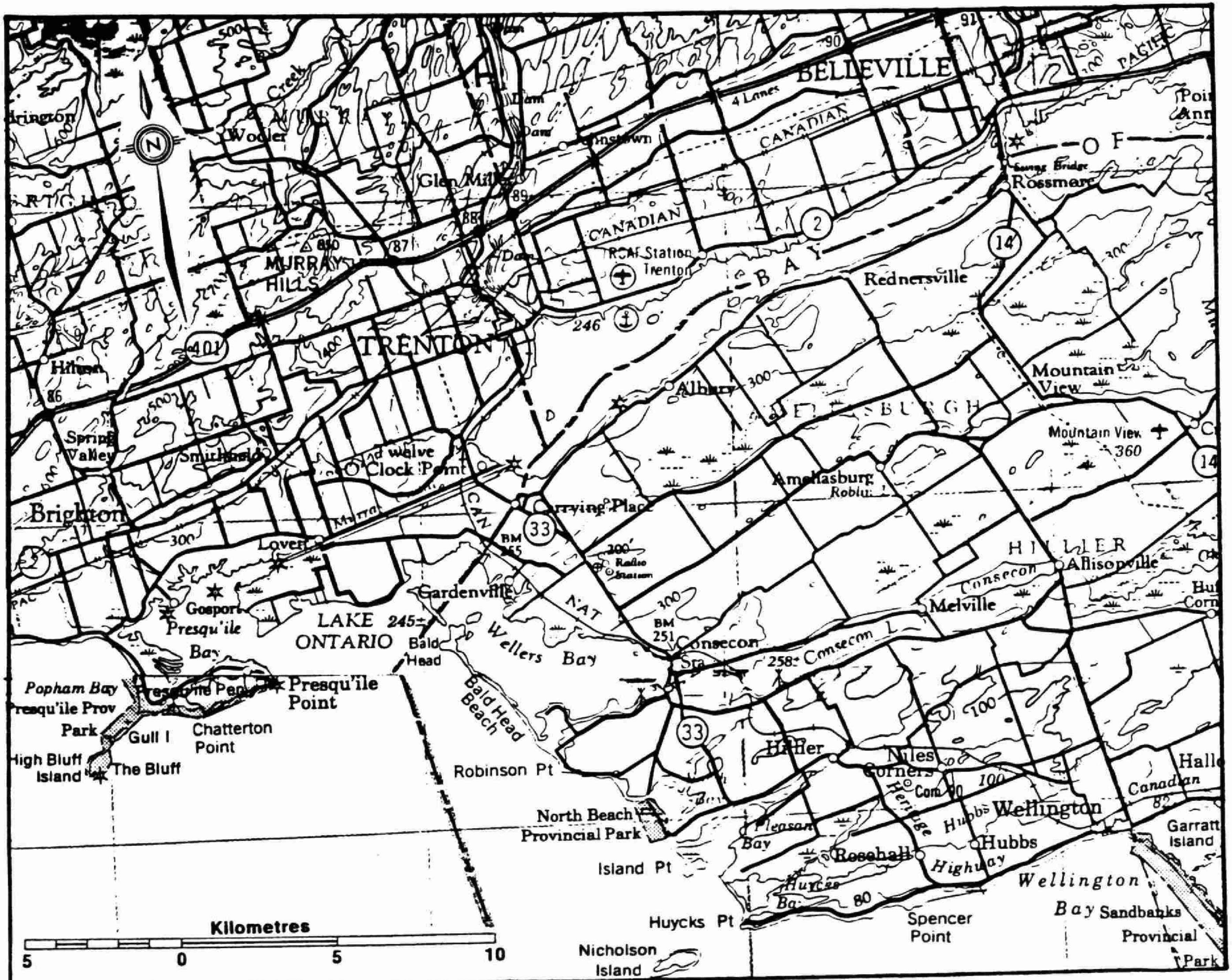

Figure 5 Topographical and road map of area around source flushing water.

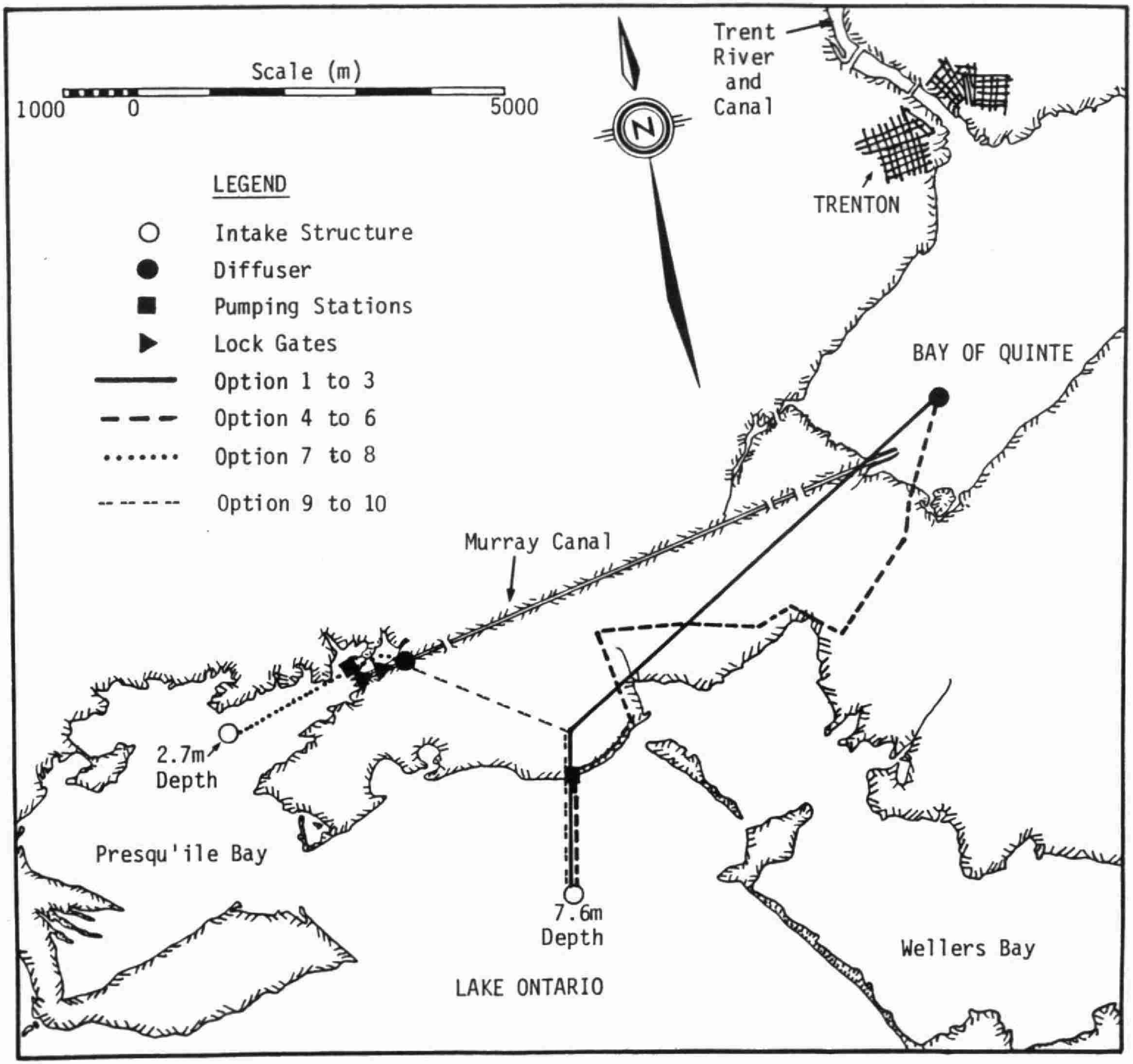

Figure 6 Plan view of proposed options.

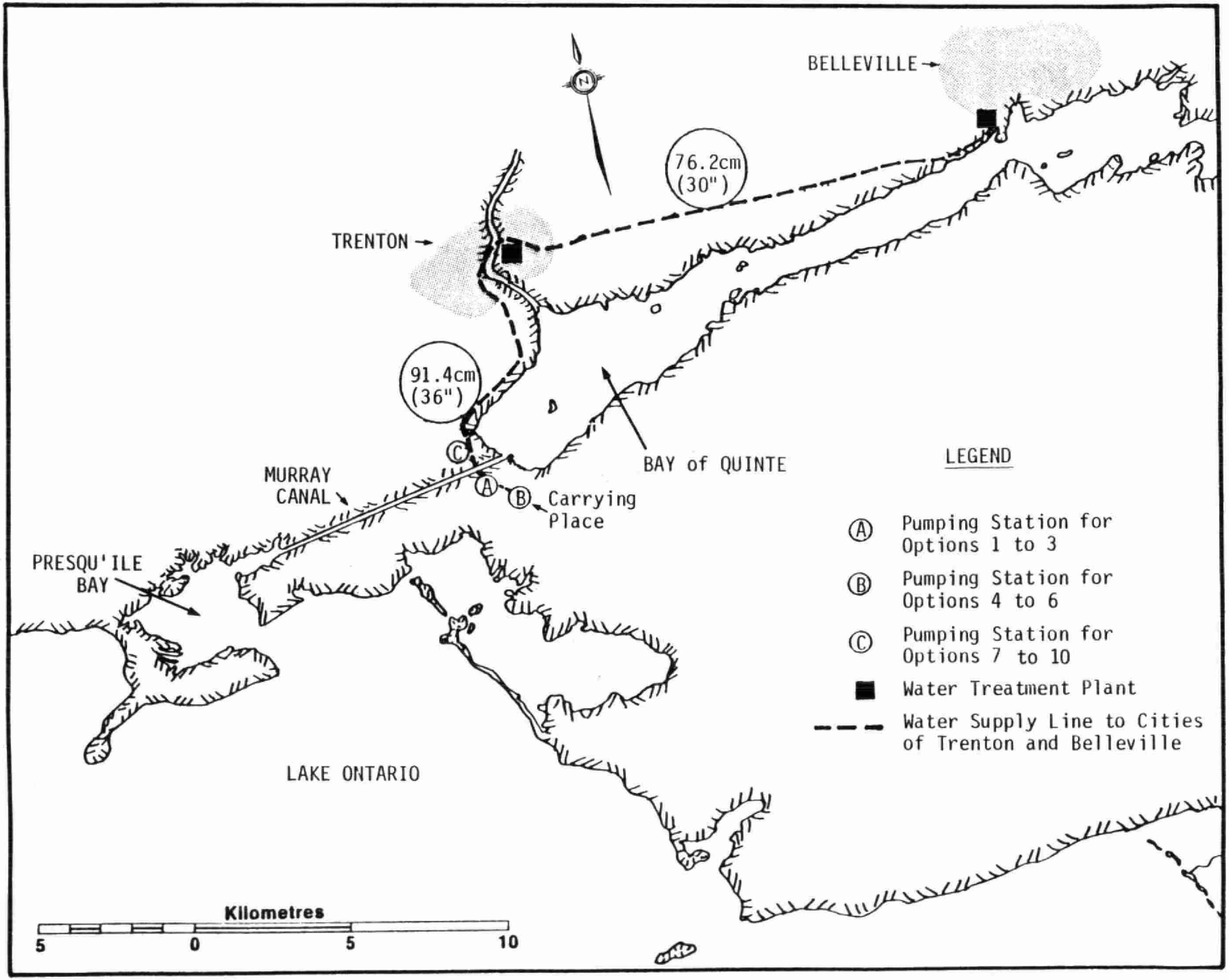

Figure 7 - Proposed water-main to Trenton and Belleville Water Treatment Plants

Remedial Action Plan
Plan d'Assainissement

Canada Ontario

Canada-Ontario Agreement Respecting Great Lakes Water Quality
L'Accord Canada-Ontario relatif à la qualité de l'eau dans les Grand Lacs